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LIGHTING FOR SEEING

GENERAL ELECTRIC COMPANY
NELA PARK ENGINEERING DEPARTMENT
Cleveland

LIGHTING *for* SEEING

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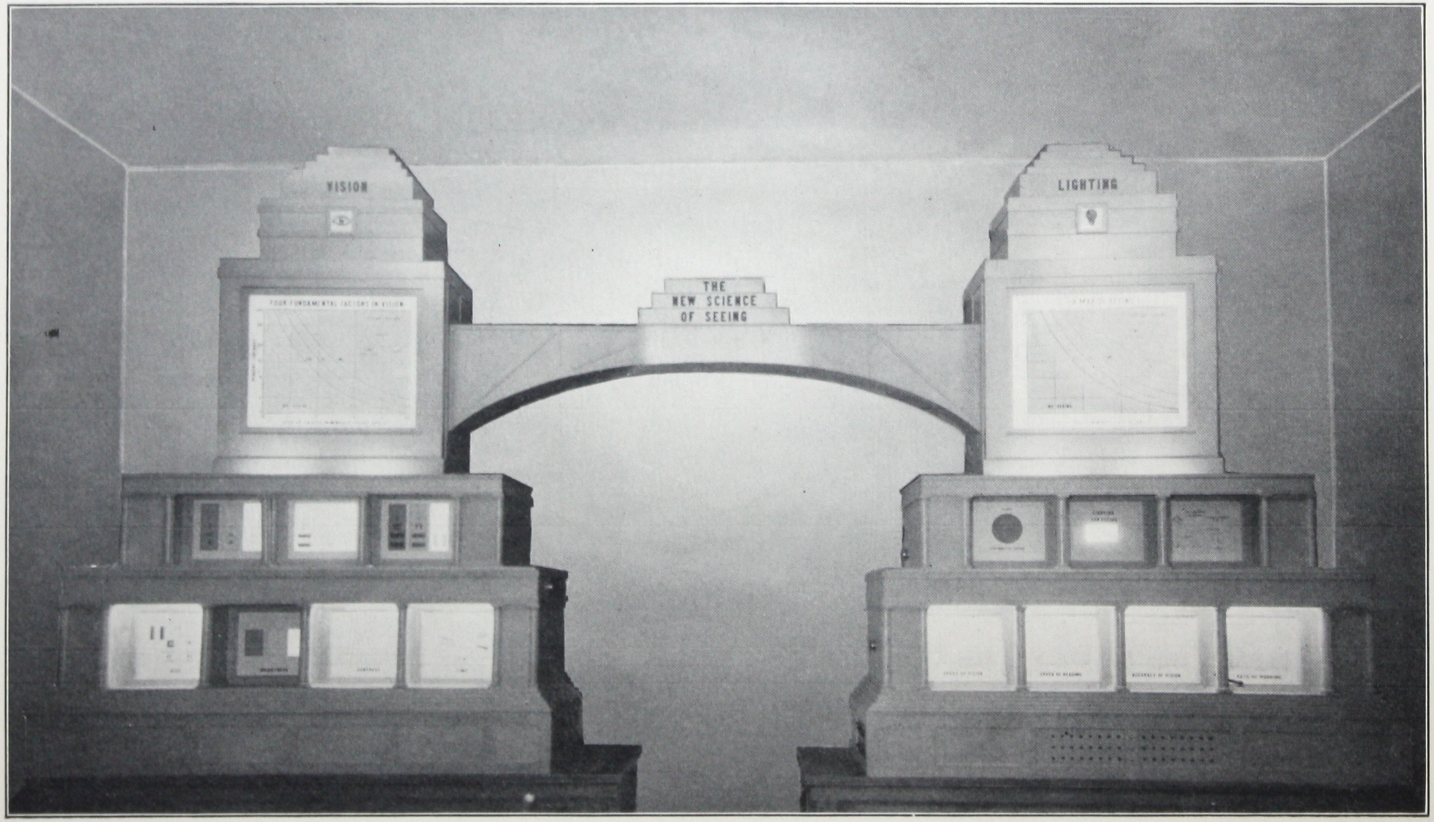


A demonstration of some of the principles of lighting and vision.

Preface

Seeing is the result of a partnership of lighting and vision. Extensive though incomplete knowledge is available pertaining to the eyes and to the visual sense. The optical profession deals with this partner which by means of lenses, if necessary, is best fitted for its work. Lighting is a relatively new art in whose accomplishments the lighting profession can take justifiable pride. However, relatively little has been accomplished in the development of the partnership of lighting and vision which results in seeing. Since artificial light has become highly controllable in quality, quantity, and distribution, we have the need of, and opportunity to develop a new science—seeing. This bulletin presents systematized glimpses of the results of scientific investigations, which aim to show that this new science of seeing is in the making. The first section of this work presents relations between light, lighting, and vision beginning with purely scientific data and progressing toward lighting practice. The second section presents interpretations of some of these data into terms directly applicable to lighting practice and suggests the possibilities of many other interpretations. The scientific basis of satisfactory demonstrations of the influence of lighting upon seeing is discussed and successful demonstrations are described and illustrated.

The work is by no means complete, but at least a complex subject is being unraveled and practicalized. Upon a foundation of this new science, the seeing specialist has an opportunity to develop and to serve the work-world and to aid a half-seeing world to conserve eyesight and to utilize it more profitably.

LIGHTING *for* SEEING

PART I

THE NEW SCIENCE OF SEEING

The long age of *mere* artificial light passed into history with the advent of gas-mantles and electric lamps. The era of *more* light had arrived and interest in illumination was born. Eventually the illuminating engineer appeared and he began to preach the gospel of foot-candles upon a horizontal work-plane. During the present century great strides have been made in the production of artificial light and we now have highly controllable artificial light at a relatively low cost. As a consequence, the possibilities of lighting have been greatly extended and scientific interest has correspondingly deepened.

To those who look at artificial lighting from this viewpoint, a lighting art presents itself which is destined to overflow in all directions those activities commonly known as engineering. This lighting art will be almost as extensive and as complex as human activities. The eyes as doorways of light are the main passage between the complex exterior world and our complex consciousness. Everywhere and in every way in which these doorways of light are used, light is essential. The potentiality of lighting includes much more than the physical and engineering aspects. Most of it is founded upon psycho-physiological sciences which in respect to lighting are little appreciated by the many and are being developed by very few.

As we pass through the foot-candle stage, one of the new branches of the future lighting art will be lighting for seeing. However, before it can be evolved with certainty we must build a new science of seeing. There is no more difficult field of research for those of long experience and interest; and for those possessing little acquaintance with the underlying sciences there are pitfalls on every hand. These are the reasons for the scarcity of reliable data and the slow growth of the science. Technique and methods are still in the process of development so that even reliable data of qualified investigators can seldom be intimately compared or correlated.

Helmholz and others left us a heritage of knowledge of the visual organ and sense but relatively little pertaining to lighting

and vision. It is obvious that seeing is a partnership of lighting and vision. With modern artificial light controllable in every respect—quality, quantity, distribution, diffusion, direction—we have control of the external partner. Over the internal partner we have no control excepting the application of lenses to sharpen the visual tool and otherwise put it in the best condition. A study of this partnership is necessary for the development of a new science of seeing.

In the limited space of this discussion we can do no more than to attempt by means of a few glimpses to convince the lighting specialist that such a science is being developed and that herein lies opportunity to evolve into a seeing specialist which the work-world is in need of. On the one hand, the members of the lighting profession are dealing with lighting and on the other the optical profession are dealing with vision. For the most part these two are separated and are concerning themselves each with one of the partners of seeing. Who will be the seeing specialist of the future; one of these who learns to deal with the partnership, or will it be someone else not yet upon the horizon?

Seeing is a Partnership

In Fig. 1 is a graphical representation of the partnership of vision and lighting. The optometrist can get the eye in best condition to do its part. The other partner of seeing is at present in the hands of the lighting specialist. The most obvious factor in lighting is quantity or foot-candles. Even with the light well diffused from an approved fixture a certain degree of reduced visibility is due to the so-called glare from the light reaching the eye directly from the lighting unit. Light may be properly distributed—directed and diffused—upon the object to be seen and a proper level of illumination may be supplied. Backgrounds are usually ignored but they can have a great influence upon the visibility of an object. The light from the object and surroundings is not usually recognized as glare but it does reduce visibility. It is unpreventable glare, usually of such mild form as to be ignored, but it is inherently present under the best lighting conditions. It tends to close the pupil and to decrease retinal sensibility. The net result of more light at the object and better lighting of it is improved seeing, notwithstanding the unpreventable glare. In fact, seeing is a result of all these major factors and many minor ones.

PART I—THE NEW SCIENCE OF SEEING

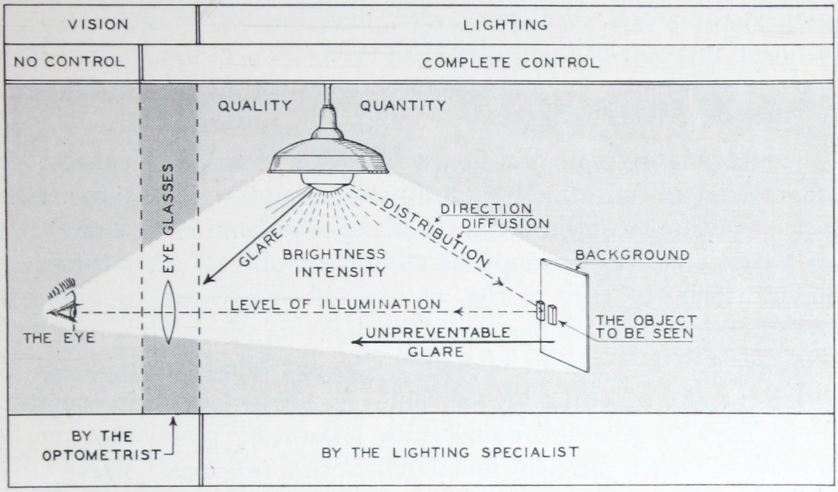


Fig. 1—The optometrist and the lighting specialist are partners for improving seeing and conserving eyesight.

Certainly, level of illumination is highly important but it is far from all-important. As lighting for seeing develops, the foot-candle decreases in value as a description of lighting conditions. At the present time it is interesting to note that the few foot-candles which represent the average levels in artificial lighting are only one-thousandth of the levels of illumination outdoors under which human eyes developed. Coincident with coming indoors to greatly restricted levels of illumination, the seriousness of the work which human eyes were called upon to do greatly increased. Is not this the clue to the general defectiveness and weaknesses of vision?

The foot-candle is only a measure of intensity of illumination. It is not a measure of seeing. As an influence upon seeing its value is not fixed; for, other conditions remaining the same, the effectiveness of a foot-candle, as a direct aid to seeing, diminishes as the level of illumination increases. To double our ability to see it is necessary to increase the level of illumination many times if other factors are not altered. The effectiveness of an additional foot-candle depends upon at least three primary factors: (1) the visual difficulty of the work which the eyes must perform; (2) the manner in which the additional light is used; and (3) the level of illumination to which it is added. But it is also possible to alter

quality, direction, diffusion, and distribution of light with a resulting increase in the ability to see in many cases.

A "Seeing-Meter" Needed

Unfortunately, there is no such device as a "seeing-meter" of universal application. If such an instrument were available, the task of raising the present low levels of illumination to values that are visually desirable, would be greatly simplified. The handicaps under which the eyes of the work-world are operating would be presented in a positive manner. The lighting specialist would have a measure of the benefit of lighting to aid him in developing his technique and in selling his product. At present, such information is obtained by slow and painstaking laboratory researches and by limited and often unscientific tests in actual practice. These data, while convincing to those who carefully study them, lack the simplicity of meter readings. A clear understanding and thorough appreciation of the value of lighting is frequently prevented by the difficulty of separating it from a maze of confusing and irrelevant factors.

The value of lighting is usually appreciated when sufficiently low levels of illumination are compared with relatively high levels. In such cases, light is its own salesman when its contribution to better seeing is obvious. In a sense, the user of light thus functions as a "seeing-meter," but very generally in an insensitive and qualitative manner. In other cases where the improvement in seeing resulting from an additional 5 or 10 foot-candles does not appear impressive to the user of light—compared with its cost—it is well to remember that a human being is a very poor seeing-meter. The eyes not only have the difficult task of attempting to appraise quantitatively the improvement in seeing, but the individual cannot determine quantitatively the benefit derived in the conservation of his eyesight and energy. The latter has not been performed even in the laboratory with any appreciable degree of certainty.

In the light of our present knowledge of the science of seeing, it does not seem likely that a seeing-meter—integrating a host of factors such as quality, quantity and distribution of light, glare, contrast, accuracy, speed and comfort—will be available. It is possible to devise certain "measuring-sticks" which will yield

measurements on particular phases of seeing and which can be made simple enough to be of service to the lighting specialist for demonstrating the partial value of better lighting. What the new science of seeing is concerned with eventually is the best combination of conditions which enables us to see most easily, most accurately, most safely, most quickly and most comfortably. It is concerned with the greatest productiveness and with complete conservation of vision and of other human resources which are drained through the process of seeing.

Science Founded on Measurements

The development of any science depends upon quantitative measurements. The methods of obtaining these in the science of seeing are comparable in complexity with those of the behavior of human beings and are very unwieldy compared with the measuring instruments of engineering and the physical sciences. This fundamental complexity must be appreciated if mistakes and discouragement are to be avoided and if progress is to be made in lighting for seeing.

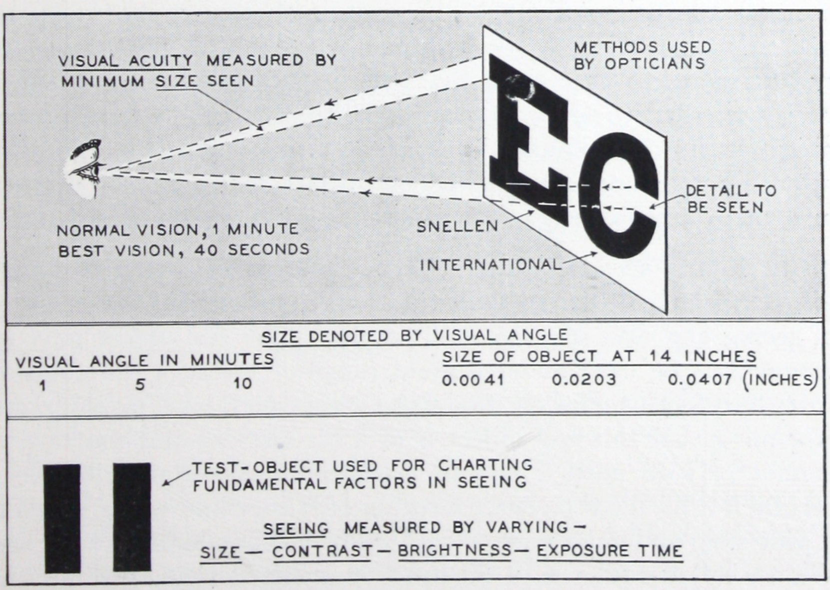


Fig. 2—Measurements on seeing involve the usual complexities encountered in measurements on human behavior.

Certain optical methods of measuring vision are indicated in Fig. 2. Actually, those in general use measure visual acuity or the threshold size or separation of objects. As a measure of size the seeing specialist must begin to use the angle subtended at the eye by an object or by the distance between adjacent objects or details. Size becomes a matter of subtended angle of critical details. To give some idea of this unit of size we have shown in Fig. 2 the visual angle in minutes corresponding to three sizes of object at the normal reading distance of fourteen inches. In the early years of our work we found visual acuity and the usual test-objects inadequate for the study of seeing. After devising and using various simple test-objects, we developed the one shown in the lower left of Fig. 2 and have used it in a series of investigations conducted continuously for many years. Eliminating color from consideration, we began a systematic study of the fundamental variables of the object—*size*, *contrast*, *brightness*, and *time of exposure*.

Vision has the peculiarity of being a variable tool. When we get down to fine measurements we cannot find a sharp boundary between seeing and not seeing an object. When the conditions are such that it is difficult to see a given object, we may see it at one moment and may be unable to see it the next moment. Furthermore, to be certain that one does recognize a test-object it is necessary to alter its position. In this case we rotate the object in its own plane. Another refinement which is approved in such researches is to expose the object to vision, for a given interval of time rather than to expose it for indiscriminate intervals.

In Fig. 3 an attempt has been made to construct a simple diagram which illustrates the limitations in measuring the clearness of seeing and also some general results. The test-object may be assumed to be used under a great range of levels of illumination from zero foot-candles on the left to a very high level on the right. Assuming that this test-object is of a certain size and contrast, it cannot be seen until it and its background are illuminated to a certain level. We then enter a region of border-line seeing which is a wide strip and not a narrow border-line as boundaries usually are. What shall we take as a measure of seeing? Certainly not the conditions under which it can be seen only one-half the total times it is presented or looked at. Shall it be the point of 100 per cent

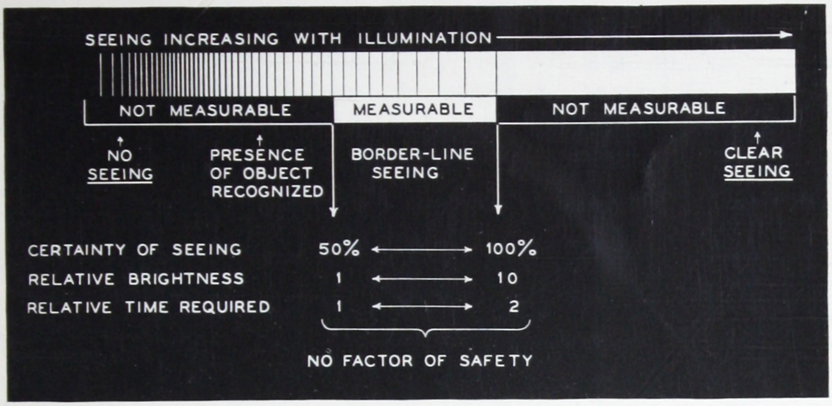


Fig. 3—Measurements on seeing can be made only at the visual threshold or the border-line between seeing and not seeing.

certainty? If so, it takes ten times the illumination or twice the time for 100 per cent certainty of seeing as for 50 per cent certainty. This region of border-line seeing is the only measurable region. Obviously, no measurements of seeing can be obtained when one cannot see the object. Likewise, after the lighting conditions have reached the point where one can see the object every time it is presented to the eyes, no measurements of this kind can be made. However, one can not say that seeing does not become easier if the illumination is still further increased. Measurements of eye-fatigue, ease of seeing, output of visual effort, etc., which have generally defied investigation as yet are sorely needed in order to reveal the relation of lighting to the conservation of eyesight and human energy. Some data already point in this direction.

In our work we usually assume 50 per cent certainty of seeing to be the border-line of seeing.

Four Fundamental Factors

Our ability to see an object depends upon at least four primary variables—size, contrast, brightness, time of exposure. Two visual tasks may be equally difficult when each of these factors differs as indicated in Fig. 4. *Size* is measured in visual angle—minutes subtended by the object at the eye. *Contrast* is defined as the ratio of the brightness-difference between the object and its background to the brightness of the background and for simplicity is expressed as per cent contrast. A perfectly black object on a perfectly white

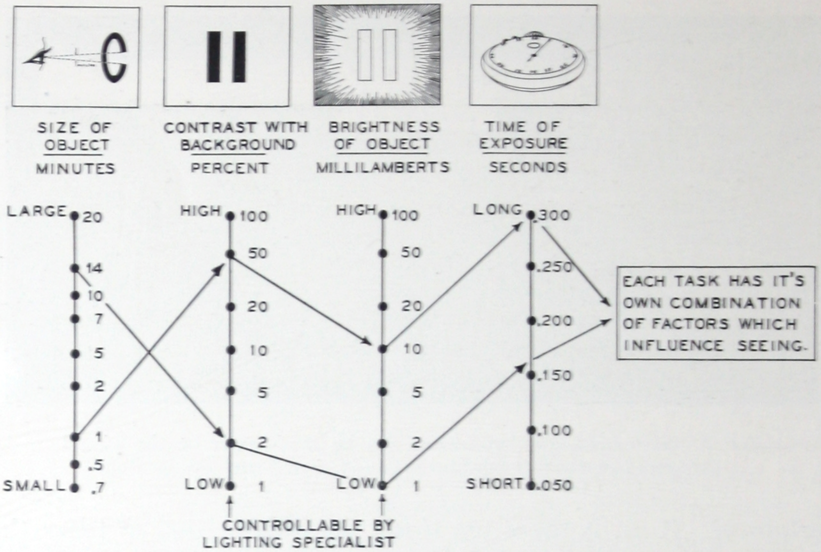


Fig. 4—Clear seeing results when fundamental visual factors are above certain limiting values. These fundamental factors are mutually complementary; that is, a deficiency in one may be compensated by the augmentation of one or more of the other factors. In this figure, the two combinations of visual factors describe conditions of equal visibility.

background has a contrast of 100 per cent. *Brightness* usually means the brightness of the background because the object to be seen is usually small and actually the background is a part of the thing seen. If the objects or details cover an appreciable part of the background, such as a page of printed matter, the brightness is the average brightness.

The size of an object just visible depends upon all the factors of light and of lighting. Assuming every factor constant excepting intensity of illumination, the minimum size of an object just visible, or rather the minimum spacing between critical details which can just be resolved by the average normal eye at a distance of fourteen inches, is as follows:

Foot-candles............	1	10	100
Size of object in inches...	0.00467	0.00357	0.00264
Relative size of object....	100	76	57
Relative visual acuity....	100	131	177

It is seen that approximately the same increase in visual acuity is obtained by increasing the level of illumination from 1 to 10 foot-candles as for an increase from 10 to 100 foot-candles. These results apply to border-line seeing at which seeing is only 50 per cent certain.

In passing, let us take a glimpse of the relation of the time required to see an object and of the certainty of seeing. From one investigation involving 60,000 observations the results obtained were as follows:

Per cent certainty of seeing	100	80	50
Relative time required to see object	100	63	48

Analyzing Seeing

In analyzing any visual task we have to consider the characteristics of the light, lighting, visual object, and of vision. The only physical characteristic of light is its spectral character. Color is a psycho-physiological characteristic sometimes important in a way differing from that of spectral character. The characteristics of the visual object are always size, contrast, brightness, and sometimes exposure-time, color, and spectral reflection or transmission. Fundamental characteristics of vision are retinal sensibility to size, brightness, brightness-difference, and time. Some of these characteristics are influenced by light or lighting and some are born of these. The actual size of an object is fixed but its apparent size depends upon such factors as shadow, highlight, background, and brightness. Some of the characteristics of the eyes—the visual tool—are fixed but some are influenced by lighting. Among the latter are pupil-size, which varies with the lighting, brightness-level, and brightness distribution. Pupil size in turn influences definition, resolving power, adaptation, and brightness of retinal image.

The relationships that exist between the four fundamental variables, *size*, *contrast*, *brightness*, and *time of exposure* are shown by the following series of charts. In Fig. 5 is presented the relationship between size and contrast for constant brightness of visual field and for constant time of exposure. If the combination of size and contrast is such that it lies within the black area, the object is invisible. The upper edge of the black area, therefore, denotes the threshold or "border-line" of seeing. The shaded area indicates the region in which measurements on seeing are possible. (See Fig. 3.) The white area represents the region of clear seeing.

One of the first steps which the lighting specialist should take toward becoming a seeing specialist is to interpret foot-candle-levels into brightness-levels. By indicating the reflection-factor

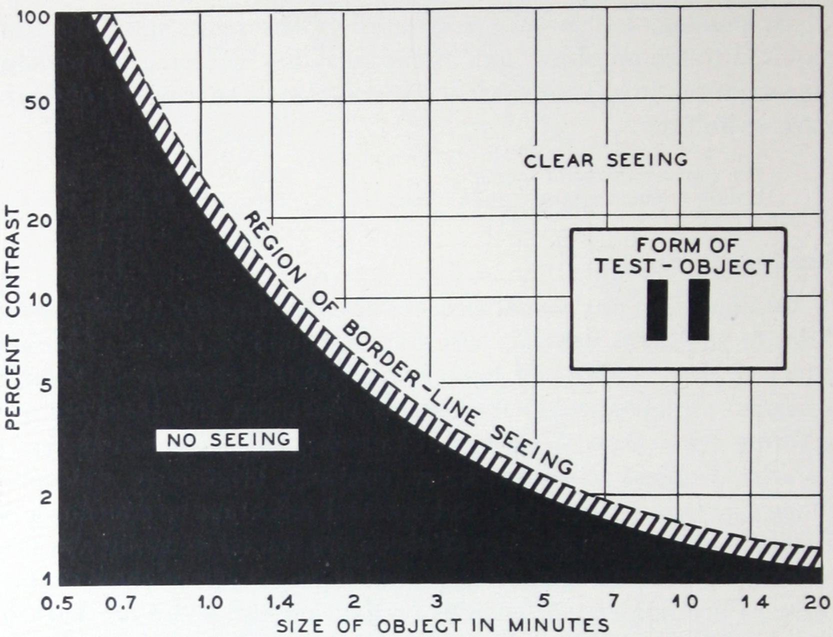


Fig. 5—The relationship between the factors of size and contrast of a test-object of the form shown.

the foot-candle-scale becomes a brightness-scale. The lower scale (Fig. 6) is in foot-candles upon a surface of 80 per cent reflection-factor and the upper one in foot-candles upon a surface of 8 per cent reflection-factor. The two scales thus are identical as brightness-scales but the values of foot-candles on the upper scale are *ten times as great* as those on the lower. These two reflection-factors include most of the range met in the practice of lighting and this method of plotting data certainly emphasizes a glaring fault of the foot-candle as a measure of lighting for seeing.

Interpreting Data

This is well illustrated in Fig. 6 in which the relation of brightness-level and the precision of seeing is presented. The visual task was primarily the setting of the lower pointer so that its point was directly below the upper one. These were seen against a background of 80 per cent reflection-factor. The decrease in error of setting with increase in brightness-level is shown for two conditions: (1) when the surroundings outside the white background were not illuminated, and (2) when the surroundings were illuminated to the same brightness as the background of the

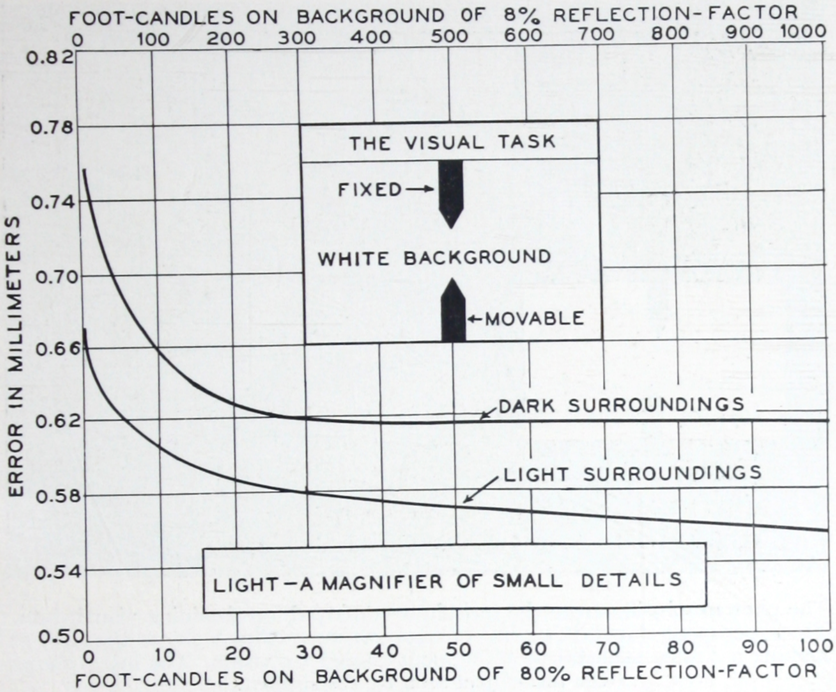
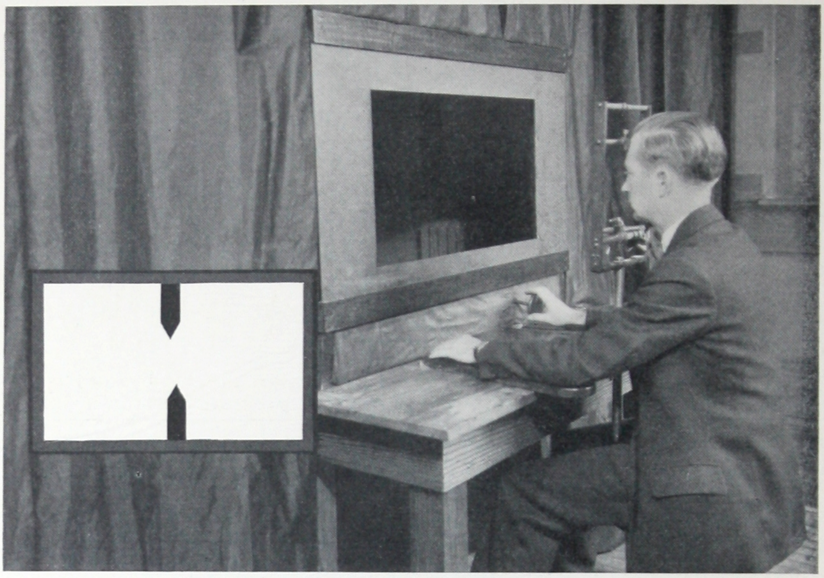


Fig. 6—The interpretation of visual data is incomplete if foot-candles only are considered. Reflection-factor determines the effectiveness of the foot-candles in producing conditions for clear seeing.

object. If these results are interpreted narrowly one might conclude that in the case of the usual bright surroundings most of the advantage of more light on the background was obtained at 30 foot-candles. However, consider steel scales and the slight contrast between the rulings and the background, and also the low reflection-factor of the background. If the reflection-factor of the background (Fig. 6) had been 8 per cent—a dark gray—the foregoing interpretation placed upon 30 foot-candles would apply to 300 foot-candles (upper scale). It will be noted that accuracy continued to increase as far as we carried the investigation. It was still increasing at 100 foot-candles on a white background. Besides this increase, we believe there are other advantages which have defied measurement. Interpreting such data as presented in Fig. 6 in terms of general foot-candle practice we must conclude that lighting for relatively easy visual tasks is generally inadequate and that, for the more difficult ones, where details, contrasts,



The photographs illustrate the technique employed for obtaining visual data. The experiment shown is typical of many others. Fig. A shows the subject making a simple mechanical adjustment guided by vision. The insert shows the test-object seen by the subject.

Fig. B—This apparatus automatically records the accuracy with which the subject keeps the two pointers (shown in insert of Fig. A) in alignment. In this particular experiment, 450,000 observations were taken in order to obtain sufficient data to plot a single curve.

and reflection-factors are small, the present levels of illumination are very low. These considerations give us courage to recommend levels of hundreds of foot-candles of proper quality and distribution. In the present stage of economics it has led us to the conclusion that highly specialized localized lighting* superposed upon general lighting is necessary for the development of lighting for best seeing.

The following charts present the various relationships in the same way except that the region of "no seeing" (below the curves) is not indicated by a black area.

In Fig. 7 is shown the relationships between size and contrast for brightness of visual field of 1, 10, and 100 millilamberts respectively.

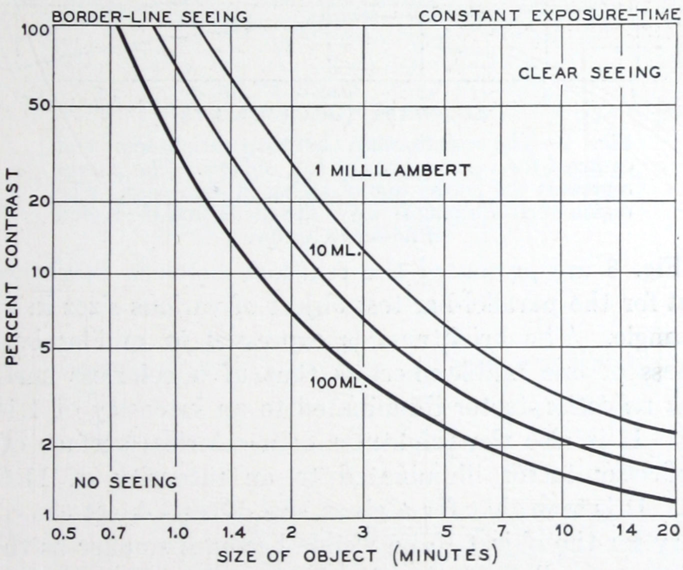


Fig. 7—The relationship between size and contrast for various brightnesses. Of the four fundamental factors, brightness is the one most readily controlled by the lighting specialist.

As the brightness-level decreases either the minimal size or minimal contrast or both must be increased if the object is to become visible again. For example, our test-object of 2.5 minutes visual angle must have 5 per cent contrast to be visible at a brightness-level of 100 millilamberts. If the brightness-level is only one millilambert, about 20 per cent contrast is necessary to render it visible. Contrast is a very important factor in seeing.

General Lighting Plus, by M. Luckiesh; TRANS. I. E. S., Vol. 24, 1929, Page 233.

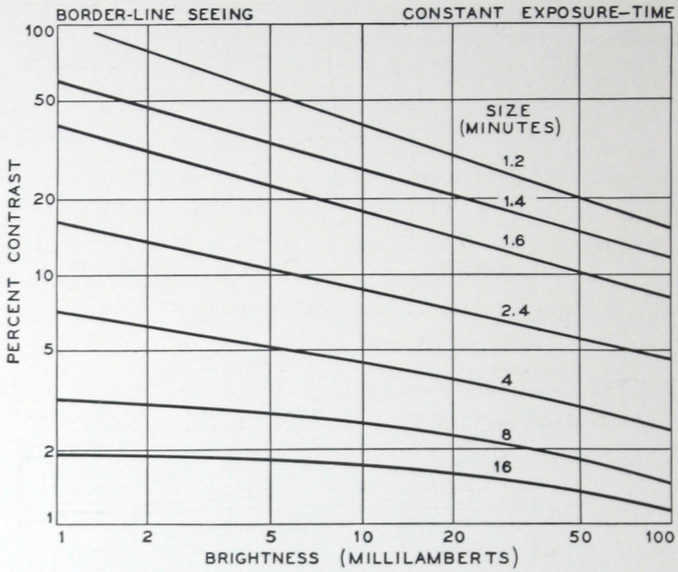


Fig. 8—The relationship between brightness and contrast for various sizes of test objects. The curves represent the border-line of seeing in each case. The region of clear seeing is above the curve, and the region of no-seeing below.

In Fig. 8 are presented the relations between brightness and contrast for the parallel-bar test-object of various sizes in minutes visual angle. The brightness is expressed in millilamberts. A brightness of one millilambert is that of a colorless surface 80 per cent reflection-factor illuminated to an intensity of 1.16 foot-candles. It is also the brightness of a colorless surface of 8 per cent reflection-factor illuminated to an intensity of 11.6 foot-candles. It is seen that for a given size of test-object the contrast necessary for the object to be visible becomes smaller as the level of brightness (or illumination for the same background) increases. This minimal contrast decreases more rapidly for the smaller objects than for the larger ones.

In Fig. 9 the relations between size and brightness for various contrasts are shown. As the brightness-level increases the minimal size of a barely perceptible object decreases.

In Fig. 10 are presented the relations between size and contrast of our test-object for various exposure-times. Although in certain cases speed of vision is important it is seen that usually it is less important than size, contrast, and brightness-level. The reaction-time of human beings has certain inherent limitations beyond which it cannot be increased.

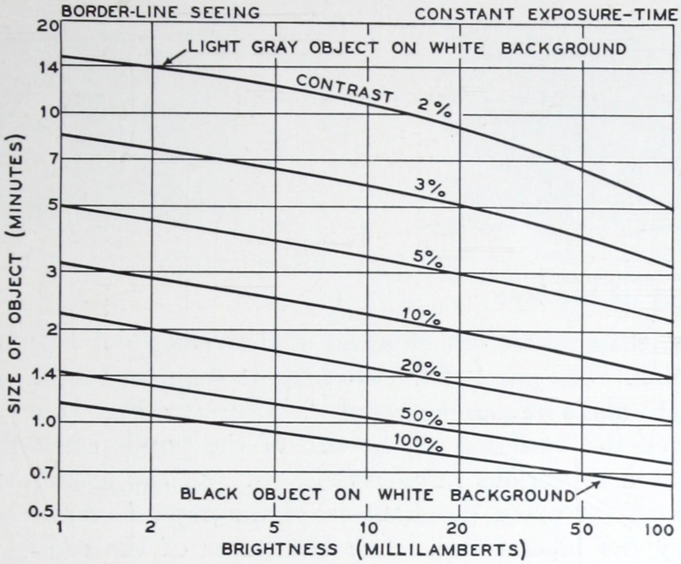


Fig. 9—The relationship between size and brightness for various contrasts. The powerful influence of the factor of contrast in seeing is obvious.

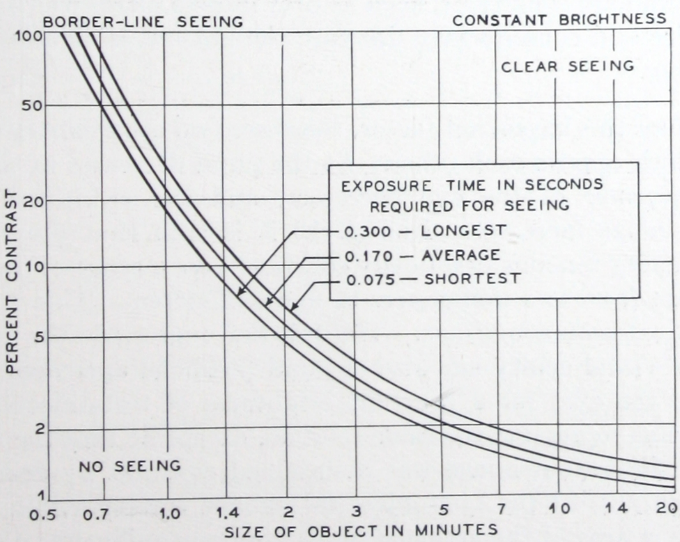


Fig. 10—The relationship between size and contrast for various exposure times.

Behavior of the Eye

Now let us take a few glimpses of the visual tool as influenced by lighting. The pupil of the eye is quite temperamental and it is difficult to make measurements of it. However, Fig. 11 represents fairly well the variation of the size of the pupils when the eyes are exposed to various brightness-levels. As the brightness-level of the work increases, the diameter of the pupil decreases as indicated by the broken line. The brightness of the retinal image diminishes in proportion to the area of the pupil or the square of the diameter. As the brightness-level increases, the light effective for seeing diminishes as indicated by solid line. Although under the best lighting conditions the pupil-size decreases with increase in brightness-level, one of the aims in lighting for seeing should be to eliminate conditions, such as preventable glare, which reduce pupil-size and consequently decrease the amount of light effective for seeing.

Besides this important factor, there are two other purely optical ones which oppose each other. As the pupil decreases in size, the *resolving power* of the eye decreases, and the *definition* of the retinal image increases. In Fig. 12 it is seen that the relative visual acuity remains practically constant over a range of pupillary diameters from two millimeters to five millimeters. This is shown for two extreme conditions. The full line represents the relation between visual acuity and size of pupil (artificial apertures placed close to the eye) for a constant brightness of test-objects. The broken line represents the same relation, excepting that the brightness of the retinal image was maintained constant by decreasing the brightness of the test-object in amount corresponding to the increase in area of the artificial pupil from one millimeter diameter upward. The actual minimal size of the object visible under the

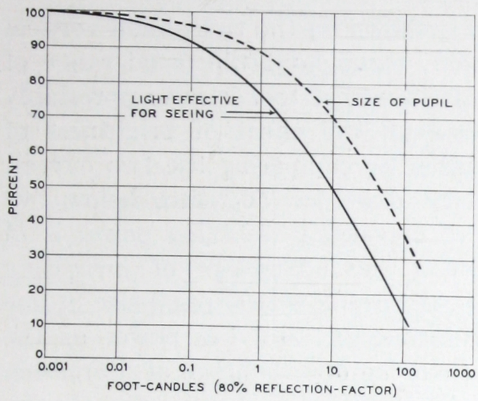


Fig. 11—As the level of illumination is increased, the pupils of the eyes contract and the amount of light reaching the retina of the eye is not raised in the same proportion as the level of illumination.

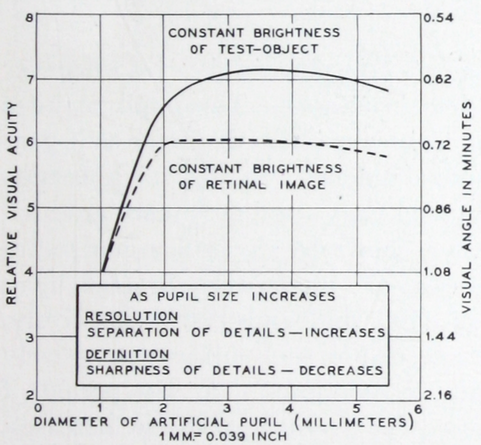


Fig. 12—The pupils of the eyes may be compared to the iris diaphram of a camera. As the aperture is increased, the resolving power increases but the definition of the picture decreases.

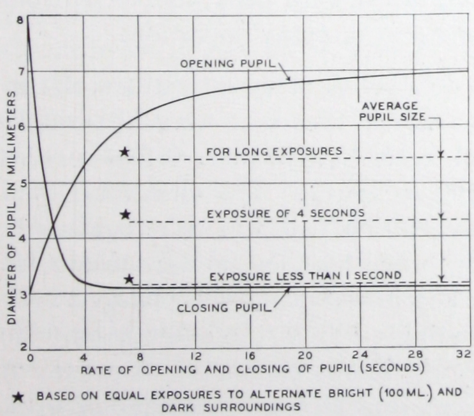


Fig. 13—The pupils of the eyes automatically change in size with fluctuations in amount of illumination. The speed of operation is much greater for increasing than for decreasing quantities of illumination.

conditions of the investigation is shown on the right-hand vertical scale. These data indicate that, throughout the usual range of pupillary size, the sharpness of the visual tool is not appreciably influenced by pupil-size. However, the effect of brightness of retinal image is important as seen by comparing the two curves. Apparently, after the pupillary diameter decreases below two millimeters the disadvantage of decreasing resolving power is of appreciably more influence than the advantage of increasing definition of retinal image. On beginning with a pupil-size of one millimeter, the advantage of increasing resolving power as the pupil-size increases is greater than the disadvantage of decreasing definition of the retinal image. There may be other factors entering very markedly at this stage but we are not certain of the importance of any such factors.

Certain involuntary adjustments take place in the eyes whenever the brightness of the visual field is altered. The pupil requires about as many *minutes* to open to its maximum diameter as it does *seconds* to close to its minimum diameter. In Fig. 13 it is seen that closing takes place rapidly and that opening is more gradual. In addition to these facts we have shown by the broken horizontal lines the pupil-size when the eyes are alternately directed upon dark and bright surroundings (100 millilamberts) respectively. When the eyes rest less than one second on each surface respectively the average pupil-size is about the minimum. As the period of exposure to each surface increases, the average pupil-size increases. These data will bear some study because they throw light upon those conditions where a worker must look back and forth from darker to brighter areas—a condition in many operations.

In Fig. 14 are the results of a series of investigations of this condition. The two fields to which the eyes were alternately exposed were of equal reflection-factor but the ratio of foot-candles upon each varied from 100/100 to 100/1. The observer varied the letters in the two apertures, and his task was to recognize the coincidences, that is, those times when both letters were alike. He recorded these by means of a key in one hand and changed both letters simultaneously by operating a key in the other hand. He was to work at the best rate which was conducive to accuracy. We had an automatic check upon quantity and accuracy of work

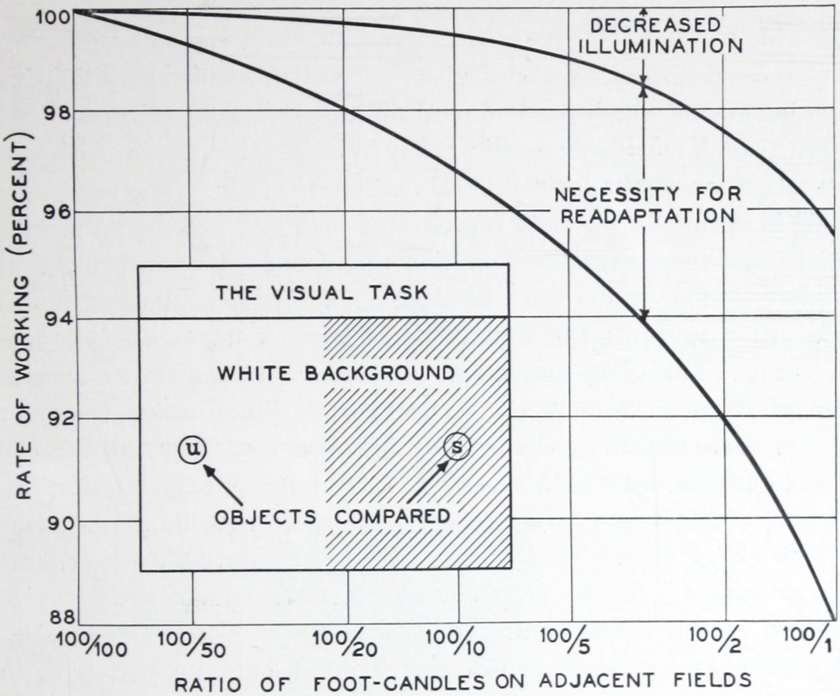


Fig. 14—If the eyes are required to alternately distinguish objects located in fields of different brightnesses (as illustrated by the insert) the necessity for adaptation to the changing brightnesses is often a serious handicap to quick seeing.

done. As the ratio of the brightness of the two fields increased from 100/100 to 100/1 the rate of working or the production of the individual decreased. The lower curve is the average rate of working for a number of individuals. The upper curve represents the decrease in rate of working due to decreased brightness of one of the test-objects or to decreased average brightness-level. The difference between these two curves represents loss of production due to the time necessary for the eyes to partially become adapted each time they look from one surface to another. Furthermore, there is a very obvious eye-fatigue which, with its results, still defies measurement. These data are interesting in connection with Fig. 13 and, even without considering eye-fatigue, eye-strain, and wasted energy, indicate the disadvantage of compelling the eyes to look rapidly from one field to another of appreciable difference in brightness.

The Effect of Glare

The deleterious effects of glare are well recognized by lighting specialists and much fundamental data is available. However, we have completed a systematic study relating this factor with our investigation of the fundamental factors of vision. The technique used in obtaining the data represented in Fig. 7 was repeated with many observers over the course of about one year excepting that a glare-source (a 100-watt inside-frosted tungsten-filament lamp) was introduced into the visual field at various angles with the line of vision. This glare-source was always at such a distance regardless of its angular position to provide an illumination intensity of five foot-candles at the eyes of the observer. The full lines in Fig. 15 are the same as those in Fig. 7 and represent the relationship of size, contrast and brightness of test-object with no glare-source in the visual field. These relations for three levels of brightness are presented. As the glare-source begins to appear in the outer portion of the visual field, visibility of the test-object decreases. It must have a greater size or contrast in order to be visible. The shaded area in each case represents the loss in visibility when the glare-source is within five degrees of the line of vision for three levels of brightness.

This loss is shown in Fig. 16 in terms of wasted light. All conditions remaining constant excepting the angular position of the glare-source, the decrease in visibility is equivalent to a decrease in the level of illumination of the test-object. Assuming the intensity of illumination to be 100 per cent when the glare-source was absent, the effective intensity of illumination decreases to 58 per cent when the glare-source is 40 degrees above the horizontal line of vision. The effective foot-candles continue to decrease as this angle decreases. In other words, the wasted light, when the glare-source is at an angle of 40 degrees, is 42 per cent. This wasted light increases to 84 per cent when the glare-source is at an angle of five degrees with the line of vision. Viewed in this manner glare is indeed costly; but we are also quite certain that there are other unmeasured losses. Certainly it is discomforting and fatiguing. Possibly it contributes toward permanent injury of the visual tool.

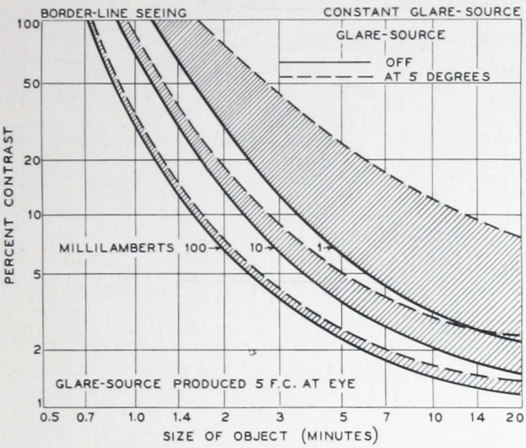


Fig. 15—The effect of glare at several levels of illumination. The area above the black solid lines is the region of clear seeing. The shaded areas show the reduction in the region of clear seeing due to a glare source at 5 degrees from the line of vision.

Fig. 16—Glare is an undesirable and usually an unnecessary by-product of lighting. The cost of glare measured by the waste of foot-candles required to overcome the reduced visibility due to glare is presented.

TABLE I
LIGHTING AND SEEING
Relation Determined under Ideal Laboratory Conditions

Foot-Candles	Relative Improvement in Seeing				
	Speed of Vision	Speed of Reading	Visual Acuity	Accuracy of Vision	Average Results
1	46	68	72	93	70
5	100	100	100	100	100
10	125	108	108	103	111
15	145	111	110	104	118
20	153	113	112	105	121
30	153	114	113	107	122
40	153	114	114	108	122

The Foot-Candle is only One Element of Lighting

Eye Defects Prevalent

Table I is a summary of some of the investigations we have made in addition to the systematic studies of seeing. All these were conducted with *black test-objects on a white background.* In fact, all conditions for seeing were *ideal.* One who narrowly interprets such data would conclude that no additional benefit accrues from increases in intensity of illumination above 20 or 30 foot-candles. In fact, such conclusions are very prevalent. But if one considers that most visual tasks do not have these maximal contrasts, that most backgrounds or surfaces have reflection-factors considerably below that of white, that experimental conditions are usually free from distractions common to work-conditions, and that such measurements as those presented in Table I do not include measurements of eye-strain, eye-fatigue, wasted energy and general wear and tear, one begins to see that much higher levels of illumination are necessary for the best work-conditions. Furthermore, one begins to suspect that by the act of coming indoors and building an artificial world of his own, man cannot necessarily escape the indelible stamp of ages of outdoor-lighting environment. Perhaps his eyes and his being need the intensities of illumination equivalent to those hundreds of foot-candles outdoors under which they evolved.

Now let us look into a condition of eye-defectiveness which is serious and almost appalling. A condensed summary is given in Table II of nearly one million human beings. Why are the eyes of young people so defective? Why do eyes become more defective with age? Does improper and inadequate lighting contribute

TABLE II
PREVALENCE OF DEFECTIVE VISION
By Groups

	Per Cent Defective	Per Cent Corrected	Per Cent Uncorrected
Public Schools	22	13	9
Colleges	40	18	22
Industries	44	19	25

By Ages

Age	Under 20	30	40	50	60	Over 60
Per Cent Defective	23	39	48	71	82	95

toward this increase in defectiveness with increasing age? Generally our organs, our arms, and our legs develop properly under normal conditions. The human race came indoors yesterday and coincidentally greatly restricted the quantity of light and greatly increased the seriousness of visual activities. There is much unknown in regard to the deleterious effects of inadequate and improper lighting upon human eyes and other human machinery. However, from the knowledge we already possess it appears that the new indoor civilization needs very badly a new science of seeing upon which a new art of lighting for seeing can be developed.

U. S. Dept. of Health Studies Lighting

From the work done by Dr. J. E. Ives* and others, we find the interesting relationship shown in Fig. 17. The sorting of mail provided a fairly constant and rather difficult visual task. Among other records made was that of visual acuity of the eyes of the workers. The lower part of the diagram shows the duration and the succession of certain periods of investigation and the foot-candles under which the workers sorted mail. The irregular line at the top indicates the average visual acuity of the workers at certain periods during this series of investigations. It will be noted that an increase in level of illumination produced an improvement in the ability of the eyes to discriminate fine detail. *The measurements of visual acuity were made under constant conditions independent of the work-conditions.*

* *Studies in Illumination*, Public Health Bulletin, No. 181, Dec. 1928.

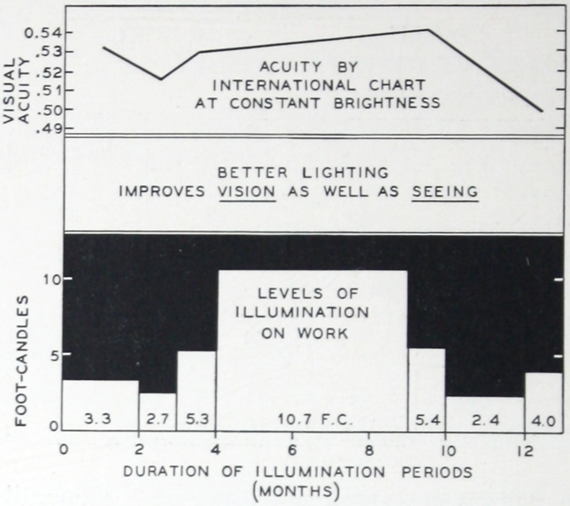


Fig. 17—The use of higher levels of illumination at work-places gradually improves the visual acuity of the workers, makes the visual task less severe, and reduces ocular fatigue.

Science Looks Ahead

The foregoing are only a few glimpses of a very complex science in the making. They have not been chosen, for their relative importance but rather as systematically arranged and fairly uniformly-spaced beacons in what was a great wilderness a decade ago. Even now it is a wilderness in which only a few clearings have been made, but we begin to see the magnitude and complexity of this new science of seeing. Its importance is not in doubt because human beings depend so much upon vision and because we have recently come indoors leaving nature's lighting behind and beginning over with relatively low intensities of illumination and with light-sources which can be used carelessly. But we have a great advantage in the controllability of artificial light. When we know how to use it at least there is no obstacle to its adequate and proper use—excepting indifference or ignorance on the part of the user.

We present with some hesitancy Fig. 18 in which we have attempted to include with definite knowledge what we believe is at least an approximation of the unknown with which we have had a vague experience but pertaining to which we have practically no measurements. The foundation of any science is accurate measurements. We actually know little about anything until we have measured it. We have already a vast accumulation of measurements but there are phases of seeing which have successfully defied measurement. The lower part of Fig. 18 is founded upon a great deal of knowledge. The upper part is no more than a diagrammatic view of what may be approximately true.

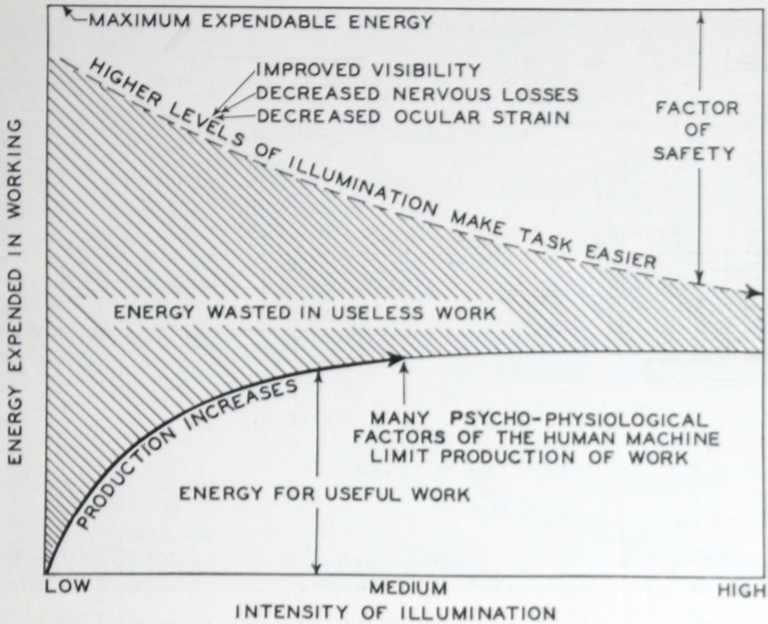


Fig. 18—An interpretation of a vital phase of the science of seeing. The human machine is considered as producing useless as well as useful work. As the level of illumination is increased, useful work increases and useless work decreases. It is believed that after the useful work has reached its maximum, there are further benefits from still higher levels of illumination.

As the intensity of illumination increases the curve representing production through visual work flattens out. Beyond this point there is little or no increase in productive work with increase in foot-candles. However, if we consider the human being as a machine whose output is expended both in useful and in useless work we gain another idea of lighting for seeing. The human being in normal work does not expend the maximum amount of energy he is capable of. When he has no light he can expend this maximum energy without productivity if seeing is involved in the task. As the level of illumination is increased useful work increases and we believe useless work decreases. When the level of illumination reaches the point where increase in useful work is prevented by certain limitations of the human machine the useless work has also diminished considerably. However, we believe that there are further benefits from still higher levels of illumination; the task becomes easier and easier and useless work continues to diminish. This is a view which has been growing upon us for years and some of our researches are being directed toward ascertaining its justification.

Tile grading requires excellent lighting for color selection; consequently Daylight Mazda lamps were installed to provide 150 foot-candles.

In addition to general lighting, localized lighting supplies 125 foot-candles for the fine work at the benches.

PART II

LIGHTING PLUS VISION EQUALS SEEING

Interpreting the Science of Seeing for Lighting Practice

Since the contributions of the lighting art include improvement in seeing, acceleration of industrial operations, and conservation of eyesight and other human resources, a complete evaluation of the benefit derived from improved lighting is manifestly difficult. Inasmuch as very little quantitative knowledge is available pertaining to the influence of better lighting upon ocular fatigue and the nervous system, we are at present chiefly limited in our appraisal of the value of better lighting to the factor of improved visibility or increased ability to see. This subject has been reduced to an exact and scientific basis for a wide range of visual conditions. It is now necessary to interpret these fundamental data into terms of everyday lighting practice in order to profit from the investment that has been made in securing them. The manner in which such data can be interpreted is almost as diversified as are the applications of artificial lighting. Obviously, it is not practicable to make analyses for every phase of lighting and, therefore, it is desirable to present the data in the form which has the greatest possible usefulness. To accomplish this it is generally necessary to depart from absolute terms and to express the results relatively. But the assumption of specific conditions cannot be avoided.

Quantity of Light

Quantity of light is one of the available means for improving seeing and, in general, is the chief tool available to the lighting specialist. When he advocates increasing the level of illumination, he must be prepared to answer two questions of primary importance:

(1) What will be the cost of the better lighting?
(2) What benefit will be obtained from it?

The cost of a certain quantity of light can be estimated accurately, but its *value* to the user has not been reduced to such a definite and numerical basis. Therefore, "cost," by reason of its preciseness, is over-emphasized in comparison with "value" which is presented only indirectly and far less simply.

The result of higher levels of illumination for improving seeing can be denoted by the reduction in size or contrast of an object required for visibility. The fundamental data are plotted in Figs. 7 to 10 inclusive. This method of appraising the visibility aspect of seeing is quite exact, but is often unwieldy for a simple demonstration of the benefit of more light. Assuming that percentage changes in such factors as size and contrast of a visual object mean little to most persons, the same data may be expressed in more familiar terms.

Method A: If we arbitrarily assume, as a practical expedient, that the full beneficence of higher levels of illumination is reached at 100 foot-candles (which is not true for the more severe visual tasks), the value of any other level of illumination can be definitely expressed. This is a practicable expedient considering the prevalent levels of illumination. For each initial level of illumination, in Table III, the improvement in visibility obtainable by increasing the "initial foot-candles" to 100 foot-candles is taken as 100 per cent. On this basis, the relative improvement for intermediate levels of illumination is presented.

TABLE III

Initial Foot-Candles		New Levels of Illumination (FC) Per Cent of Possible Improvement in Seeing (%)					
4	(FC).......	6	8	10	12	16	20
	(%)........	19	31	40	47	57	64
8	(FC).......	12	16	20	24	32	40
	(%)........	23	37	48	54	65	73
12	(FC).......	18	24	30	36	48	60
	(%)........	26	41	52	61	74	82
16	(FC).......	24	32	40	48	64	80
	(%)........	27	45	57	68	81	91
20	(FC).......	30	40	50	60	80	100
	(%)........	28	49	64	74	89	100

For example, if a 4-foot-candle installation is replaced by a 10-foot-candle system, 40 per cent of the aid that light can give to the eyes is obtained. If the level of illumination is raised from 4 to 16 foot-candles, 57 per cent of the possible benefit is obtained. Similar data are presented for initial installations from 4 to 20 foot-candles. In each case the improvement in seeing to be obtained from quantity of light is taken as 100 per cent. The 100 foot-candles is merely an arbitrary limit for the present purpose.

Size of Pupil

The abrupt change in level of illumination between daylight outdoors and artificial light indoors is an important factor to be considered in the lighting of many interiors. When exposed to the high levels of daylight illumination the pupils of the eyes are contracted to their minimum size and require about 30 seconds to open to a point of equilibrium for the lower intensity of artificial illumination. This change in pupil size may easily amount to a four-fold increase in pupillary area as indicated in Fig. 19. Thus, upon entering a store, for example, the pupils admit about one-fourth as much light as they do some 30 seconds later, as seen in Fig. 13. If the level of general illumination is actually 20 foot-candles, upon entering, the effective illumination is initially equivalent to about 5 foot-candles. The effective illumination then increases from 5 foot-candles as the pupils open, but does not reach the maximum for some time owing to the lag of adaptation. The first impression of the interior may be quite unfavorable due to the apparent low level of illumination in contrast with that of daylight outdoors.

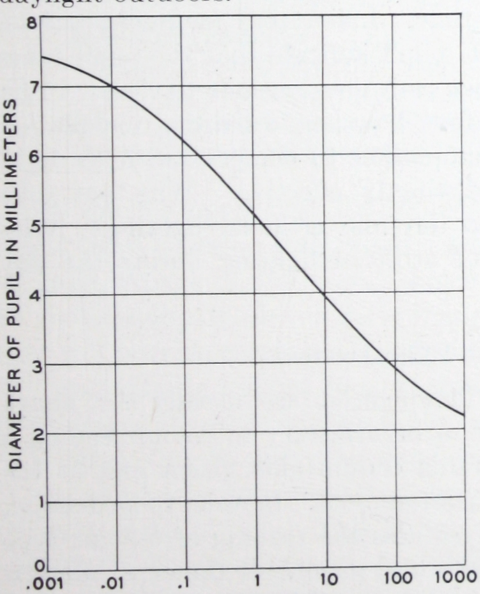


Fig. 19—The size of the pupil after 15 minutes' exposure to various brightnesses (foot-candle intensities on a white surface of 80 per cent reflection-factor).

Meanwhile, the prospective customer has had time to walk some 50 or 75 feet at a moderate gait or, if in a hurry, has traversed perhaps 150 feet. The obvious result is that some 50 to 150 feet of displayed merchandise are viewed under conditions equivalent to a foot-candle level somewhere between 5 to 20 foot-candles. In addition to the "loss" in foot-candles upon entering, the visual annoyance produced by the sudden plunge from daylight to artificial levels of illumination may be important in discounting the merit of an otherwise fine lighting installation. The

undesirability of such a situation is further emphasized by the fact that many merchants consider the front part of their stores as the most valuable from the standpoint of creating sales.

In some interiors a gradient between the high and low levels of illumination is produced by daylight from windows and entrances. In others, this feature may be almost entirely absent and in such situations the elimination of a sharp change in level of illumination could be produced by artificial lighting. The value of a more gradual change in level of illumination has already been recognized in some installations. A notable example is the lighting of the Holland Vehicular Tunnel in New York; in this instance, the level of illumination is gradually increased at both ends of the tube so that the eyes are not required to make a sharp readaptation to a far different level of illumination.

If a brightly lighted interior is entered from a darker area, such as a hall or corridor, the effect of the sharp contrast in illumination is not of importance compared with the opposite condition. The pupils of the eyes contract to compensate for the higher level of illumination in a very short time. Laboratory measurements on the opening and closing of the pupil indicate that the pupil takes about as many minutes to open as it does seconds to close. From the standpoint of visual comfort, however, a lighting installation that increases in level of illumination to compete with daylight at the entrance would be distinctly effective. Why not take these factors into account in daytime artificial lighting? Why not have higher intensities of artificial lighting during the day than at night?

An Example of Foot-Candle Effectiveness

Since the ideal levels of illumination are usually far above present levels, it is necessary to be arbitrary in recommending a level of illumination that affords comfortable vision and at the same time permits its economic attainment. In order to be definite, suppose that the visual task requires the reading of 6-point type printed in black ink on a good white paper. If the experiment is tried in which the reader is instructed to select the minimum level of illumination that appears to afford comfortable vision for extended periods, a 10-foot-candle level will represent a conservative result. The reasonableness of the demand for 10 foot-candles for

visual work of this type may be tested easily by anyone who thinks it is too high.

Now let us compare the visibility of the letters in a telephone directory, for example, with letters of the same size printed on fine book-paper with deep black ink. The reflection-factor of the low-grade paper used in the telephone directory is about 57 per cent and that for high-grade book-paper is about 80 per cent. The contrast between the "black" letters and the paper of the telephone directory is about 80 per cent, while the contrast in the other case is 97 per cent. Assuming that the size of the critical details to be seen is about 1 minute visual angle, it is found from fundamental data, relating size, contrast and brightness, that brightness-levels of 5.4 and 2.6 millilamberts, respectively, are required in order to produce threshold visibility in the two cases. In order to produce these brightnesses, 8.8 and 3.0 foot-candles, respectively, are required. The results are summarized in the following table. The data in column A apply to the telephone directory and those in column B to a book of fine typography.

Kind of printed matter	A	B
Reflection-factor of paper (Per cent)	57	80
Contrast between ink and paper (Per cent)	80	97
Brightness required for equal visibility	5.4	2.6
Foot-candles required for threshold visibility	8.8	3.0

It will be noted that the intensity of illumination should be about three times as great upon a page of the telephone directory as upon a page of the book. Since it has been concluded that 10 foot-candles is about the minimum intensity of illumination that will provide comfortable vision in the case of better printing, it is probable that about 30 foot-candles would be required for the same degree of ease of reading in the case of the telephone directory. It is interesting to note that our "desirable" level of illumination is approximately only three times as high as the threshold value for very small objects. This is but one of many cases where the lighting is barely adequate for the best visual conditions and inadequate for many other visual tasks. It is to be emphasized that these data are based on measurements of visibility and do not include considerations such as ease of reading and the conservation of human resources.

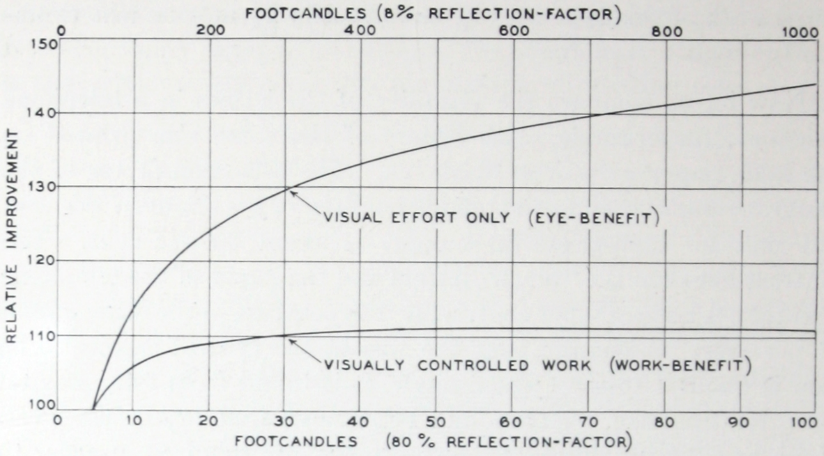


Fig. 20—"Eye-benefit" curve summarizes the results of several experiments involving simple visual recognition of test-objects. "Work-benefit" curve summarizes the results of experiments involving the performance of various tasks guided by vision.

Ocular Strain

The minimization of ocular fatigue is of primary importance in the conservation of eyesight. Unfortunately, the subject is so complicated by physiological and psychological factors that as yet it has not been reduced to exact measurements. The lack of a definite scale for the measurement of ocular strain has given the subject an aspect of the intangible, and consequently this vital phase in vision is often subordinated or ignored in favor of more obvious and probably less important factors.

Although no satisfactory and direct method has been devised to measure ocular strain, the subject can be approached indirectly and conclusions important to lighting practice can be drawn. A number of laboratory experiments were divided into two groups: (1) experiments in which the subject was required to perform visual work only and (2) experiments in which the subject was required to perform various mechanical tasks guided by vision. The results for each group are summarized in Fig. 20 in which the abscissae represent the brightness of the background (intensity of illumination for reflection-factors of background).

A comparison of the average results of the two types of experiments indicates that the advantage to the eyes of higher levels of illumination extends considerably beyond the limit of appreciable

increased production. This is illustrated in a more or less imaginative diagram in Fig. 18. It is also obvious that increased production (or work-benefit) is not obtained to the same extent that the eyes are aided by better lighting. In other words, the worker does not necessarily utilize the facilities for better seeing entirely for working as fast as possible, but rather effects a compromise and uses a part of the advantage of better lighting in making his work easier. Therefore, as higher levels of illumination are used, the "factor of safety" for the eyes is increased and ocular strain is correspondingly decreased.

Demonstrating the Influence of Foot-candles Upon Seeing

The functioning of the human machine is the result of a host of applied stimuli. The lighting specialist is, therefore, faced with a decidedly difficult task when he attempts to isolate the effect of but one factor—light—from the many that are present. The problem is difficult even in the research laboratory where elaborate precautions can be taken to minimize the number of variables and to control them. It is not unusual for the laboratory technician to take thousands of observations to determine one particular phase of the relationship between lighting and seeing. When direct, simple, and quick measurements on seeing are attempted outside of the laboratory the pitfalls are increased and the difficulties are magnified. Not only do eyes and individuals differ greatly, but the same subject will frequently give results varying over a range several times as great as the difference sought. These wide fluctuations are likely to occur not only momentarily but from one test to another. This illustrates the need for extensive foundational research data and for demonstrations based upon such knowledge so that the "spread" of results is reduced as much as possible.

Another difficulty encountered when one seeks to show the visual difference between two levels of illumination is that the eyes will temporarily compensate for the poorer condition (at the subject's expense), and by increased expenditure of energy actually perform as well as under the more favorable condition. The following brief summary of a recent experiment will illustrate this phase—and one of the pitfalls of superficial knowledge. The eyes of the subjects were tested at the beginning and again at the close of the day's work and, in addition, the subjects were required

to perform a rather difficult mechanical and visual task. The rate of working and the accuracy of and attentiveness to the work were determined. The afternoon results are compared with those of the morning in Table V.

TABLE V

THE EYES

Visual Acuity	Eye Muscle-Balance
Decreased 2%	Changed 5%

PERFORMANCE OF WORK

Attentiveness to Task	Delay in Correcting Errors	Amount of Work Done
Increased 14%	Decreased 2%	Increased 4%

It is to be noted that, although the eyes showed evidence of fatigue and strain, the performance of this specially inserted work was greater at the close of the day than at the beginning. This result is typical of that obtained in other experiments. Such a situation, in which *increasing production* takes place with *decreasing ability* to produce, forms a combination which is detrimental to the welfare of the worker and results in excessive fatigue and losses in nervous energy. The rate of working, therefore, is not an indication of fatigue, since the results often indicate the opposite effect.

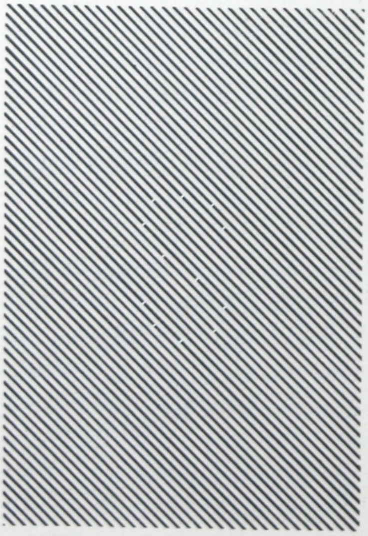


Fig. 21—The test-object is formed by breaks in the parallel diagonal lines. On this pattern is the letter "S." For the purpose of this illustration, the visibility has been increased by means of a white background in place of a gray one as actually used in the Demonstration Visual Test.

A Demonstration Visual Test*

In order to demonstrate convincingly the influence of more light upon seeing it is necessary to develop a test that will yield with certainty large differences for comparatively small changes in level of illumination. From our foundational data we know that such a test must be a visually severe one. Furthermore, the visual task required must be such that the eyes operate near the limit of their ability in order to insure constancy of visual effort. If the visual task permits the eyes to function with comparative ease, the "reserve visual ability" usually serves to absorb any change in performance that lighting might effect. Since most persons, if instructed to work at their maximum rate, will establish a rate which may be described as "not too difficult," it is highly desirable that the test be such that the eyes perform their work more or less involuntarily.

Fig. 21 illustrates a test-object that has been developed to meet these requirements. It consists of a capital letter formed by breaks in parallel diagonal lines printed on a gray background. In the illustration, however, the pattern has been printed on a white background instead of a gray one in order to show the test-object more clearly. Its primary purpose is to indicate the influence of quantity of light upon seeing and has been designed to be most effective over a range of 5 to 50 foot-candles. However, the device may be constructed so as to operate satisfactorily for other levels of illumination.

The visual difficulty of recognizing a test-object may be controlled by changes in size, contrast, or time during which it is exposed to view. Mechanical features involved in varying time of exposure eliminate this feature of control for a simple demonstrating device. In order to secure the necessary visual difficulty, at levels of illumination interesting to lighting practice, very small visual details would be required. Since the ability to see small details varies greatly among individuals, a test-object designed for "normal" vision would be indistinguishable by some persons and for many others would not provide a difficult task. However, the same degree of visual difficulty can be obtained by reducing the contrast of the object with its background without the serious objection of having an object applicable to a limited number of

*The Demonstration Visual Test can be obtained from the Lighting Research Laboratory, Nela Park, Cleveland, Ohio.


A Demonstration
Visual Test
SEEING
The Value of Lighting
Measurements of Seeing

persons. Therefore, the breaks in the parallel lines of this object were made about twice as large as the smallest size visible and a corresponding reduction was made in contrast—an important factor, as is evident from our fundamental data (Fig. 5).

The purpose of the pattern of parallel diagonal lines is not to present a maze in which the test-object (the capital letter) is hidden. The letter purposely has been made as large and as simple as possible and factors that tend to make its recognition difficult, excepting the visual factor, have been minimized. The uniformity of the parallel lines makes it quite difficult for the eyes to remain fixated on a definite part of the pattern. As a result, the normal eye-movements are greatly accelerated and the task of looking at such a pattern is a visually severe one. This fact will be readily appreciated if Fig. 21 is viewed steadily for a few seconds. However, these fatiguing eye-motions are performed involuntarily and, since the subject has so little control over the amount of visual energy expended, the performance of the subject from test to test becomes more uniform.

Four of these patterns of parallel-diagonal lines are printed on each of a number of pages of a booklet which is illustrated on page 44. Essentially, the visual test consists of recognizing the capital letter formed by the small breaks in the parallel lines of each pattern. The total time required to recognize the entire series of 52 test-objects is taken as the criterion of the effectiveness of the lighting. As experience is gained, other experiments may be tried, such as measuring the effect of glare in reducing the ability to see. This simple test has proved itself to be a valuable research tool, even in comparison with elaborate laboratory apparatus, as well as a practicable demonstration in the hands of untrained observers.

Typical Results

The results from this visual test are in agreement with previous knowledge and experience. Table VI summarizes a few of the results obtained by ourselves and by others.

The significant factor in these results is not that the average of several observers gave a substantial gain at the higher level of illumination, but that the individual results are in the same

TABLE VI

Foot-candles Increased		Increase in Rate of Working	Subjects Using the Test
From	To		
3	12	34%	Ten observers trained in making laboratory observations
6	12	18%	
12	48	11%	
24	48	6%	
6 (60 lux)	20 (200 lux)	25%	Thirty-one observers from staff of S. A. Phoebus (testing laboratory) Geneva, Switzerland
9.6	22	42%	Seven observers from Dept. of Physics, University of Washington
4	16	64%	Eleven observers from G. E. Lighting Institute, Nela Park

direction. Simplicity and certainty of demonstrating the advantages of more light are salient features of this test method.

Other Data Obtainable

Many interesting and important relations between lighting and seeing can be investigated with this test, since it does not require experienced observers or long periods of experimentation.

Experiment A: Since 40 per cent or more of industrial workers have defective vision, the benefit derived by this group from improved lighting should be a vital factor in lighting programs. The data given in Table VII bear directly upon this subject. The improvement in the lighting was made by raising the level of illumination from 3 to 12 foot-candles.

TABLE VII

Classification of Workers	Increase in Rate of Working
Group with better eyes	14%
Group with worst eyes	22%

Thus, light as a tool for seeing gives the greatest assistance to those equipped with the poorest visual apparatus. As the eyes respond so definitely to the influence of better lighting, it seems justifiable to expect a worthwhile improvement in *vision* from good lighting.

Experiment B: Subjects were instructed in the use of this test and then performed it several times. The time required to do the work varied considerably between individuals, as would be expected, since each has his own natural rate of working. By means of these preliminary data the subjects were divided into two equal groups, the "slower" and the "faster." Routine tests were then made at various levels of illumination. The results are given in Table VIII.

TABLE VIII

Foot-candles Increased		Increase in Rate of Working	
From	**To**	**Faster Group**	**Slower Group**
3	12	28%	40%
6	12	15%	20%
12	48	10%	12%
24	48	5%	6%

This experiment indicated that the group of subjects who were inherently the slower workers received greater help from the improved lighting than did the faster group. Here again, lighting acts as an agent toward balancing the inequalities in the performance of the human machine. Good lighting helps those most who need it most.

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